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Vision Research 38 (1998) 2203–2210

Vision Research

Automated visual field examination in children aged 5–8 years Part I: Experimental validation of a testing procedure

Chantal Tschopp [a,b], Avinoam B. Safran [a,*], Paolo Viviani [b,c], André Bullinger [b], Michael Reicherts [b], Christophe Mermoud [a]

[a] *Neuro-ophthalmology Unit, Geneva University Hospital, CH-1211, Geneva 14, Switzerland*
[b] *Faculty of Psychology and Educational Sciences, Geneva University, Geneva, Switzerland*
[c] *Laboratory of Action, Perception and Cognition, Faculty of Psychology, Vita-Salute University HSR, Milan, Italy*

Received 6 February 1997; received in revised form 28 July 1997

Abstract

In 106 children aged 5–8 years, we determined how much training was needed to stabilize the response strategy prior to actual visual field assessment and we evaluated the reliability and acceptable duration of automated static perimetry (Octopus 2000R). A specially designed familiarization procedure was used to train the children to: (1) gaze at the center of the visual field while paying attention to light stimuli projected onto the periphery and (2) press the buzzer only when light stimuli were perceived. The subsequent examination phase consisted of 15 successive identical blocks of 27 trials (12 stimulus trials, 12 false-positive catch-trials, and three false-negative catch-trials), and was stopped before the end if signs of fatigue appeared. Age had a marked influence both on endurance (the number of blocks performed increased significantly) and on response reliability (false-positive responses decreased between 5- and 6-year-olds). The increase in false-negative responses toward the end indicates that examination is no longer reliable, and should be stopped. We concluded that most children as young as five can undergo examination by automated static perimetry. Changes regarding learning, stimulus intensity and testing procedure are suggested in order to adapt the examination to age, level of vigilance and health condition of the children. © 1998 Elsevier Science Ltd. All rights reserved.

Keywords: Automated perimetry; Children; Endurance; Reliability; Visual field examination

1. Introduction

In adult patients, visual field examination is routinely performed using various types of automated static perimetry (ASP). In contrast, the adequacy of ASP for young children with ocular or neurological disease is still a matter of debate. The controversy concerns mostly the level of reliability that one can expect from children.

In ASP, reliable results depend on the subject having many diverse abilities: learning the correct sequence of actions, selecting the stimuli, inhibiting irrelevant responses, and maintaining central fixation. When testing children, difficulties in learning [1,2], in maintaining a stable fixation on the central target [3–7] and in sustaining concentration [8,9] are commonly reported. Moreover, Whiteside [10] has suggested that the lower peripheral sensitivity generally found in children may have a conceptual or attentional basis rather than a perceptual one. However, the question of how to adapt ASP examination to a pediatric population is still open [11]. The present study is an attempt to set guidelines for testing young children.

Normative data are needed about training, reliability, and endurance in a pediatric population. To devise a strategy for evaluating young children, we tested 106 normal subjects aged 5–8 years. We investigated three issues in particular: (1) the range of training trials needed to establish a stable response prior to actual visual field assessment; (2) the acceptable duration of such an examination and (3) the reliability of results. We found evidence that adapting the task to the psychomotor and cognitive developmental level of the subject can make standard ASP possible in young

* Corresponding author.

PII: S0042-6989(97)00368-4

children. In the second part of this study [12], we show that reliable sensitivity thresholds can be obtained by following the guidelines suggested here.

2. Material, subjects and method

2.1. Subjects

Subjects were 106 normal children (50 females) aged 5–8 years, attending full-time elementary schools in Geneva, Switzerland. Four schools were recruited because of their proximity to the hospital neuro-ophthalmology unit. The subjects corresponded to a middle-class socio-economic level and were of various European ethnic backgrounds. All children included in the study had a visual acuity of 20/20 according to the E Snellen test, and an unremarkable ophthalmologic history. Twenty-six subjects were tested at age 5, 25 at age 6, 25 at age 7, and 30 at age 8. Age criterion was ± 3 months from the child's birthday. Testing was performed with the understanding and written consent of the children's parents. The study protocol was approved by the ethics commission of the Institute of Social and Preventive Medicine, in Geneva.

2.2. Testing position and material

To optimize postural stability, the child sat in an upright position on a large saddle adjusted to his/her size, with the body tilted forward by 10° and the feet resting on a platform. The chest rested against a specially adapted support and the arms on armrests at elbow height (Fig. 1).

Subjects were tested with an Octopus 2000R automated perimeter (Interzeag AG, Switzerland). Background illumination was 4 apostilb (Asb), and test spots were 0.41° in diameter with an exposure duration of 100 ms. Stimulus intensity was measured in decibels (dB), a logarithmic unit expressing the degree of light attenuation. The 0 dB stimulus was of maximal (1000 Asb) intensity, and a 10 dB filter attenuated the light to one-tenth of this value (100 Asb). The higher the dB value, the lower was the stimulus intensity. To help dissociate the significance of the central target from that of the light stimuli, the image of a little bear (2×1 cm) was inserted in the center of the cupola, the fixation target being its navel.

2.3. Testing procedure

In all subjects, the right eye was selected for examination. The task was introduced as a tale. The light stimuli were stars coming to visit their friend, the little bear. The child was asked to look constantly at the little bear's navel. We explained that he/she would be able to see the stars without staring at them. To motivate the child to maintain a central fixation despite the presentation of the stimuli, it was said that the little bear was very happy when the child looked at him, and very sad when he looked at the stars. Children were instructed to acknowledge the appearance of a 'star' by pressing a buzzer.

Because of the mechanical characteristics of the apparatus, a sound cue (click) preceded each stimulus presentation. In false-positive catch-trials, the sound cue was followed by a stimulus of subthreshold intensity. A response to these test stimuli was taken to indicate that the subject had reacted to the click rather than to the visual stimulus, and the response was recorded as false-positive. In false-negative catch-trials, maximal-intensity stimuli were presented at randomly-selected locations of the visual field where normal (weaker) stimuli had previously been detected. Failure to respond in these trials was recorded as a false-negative response.

The actual examination was preceded by a familiarization procedure during which the children were trained to perceive the stimuli while maintaining central fixation, and to respond to the stimuli rather than to the clicks. The familiarization procedure included four

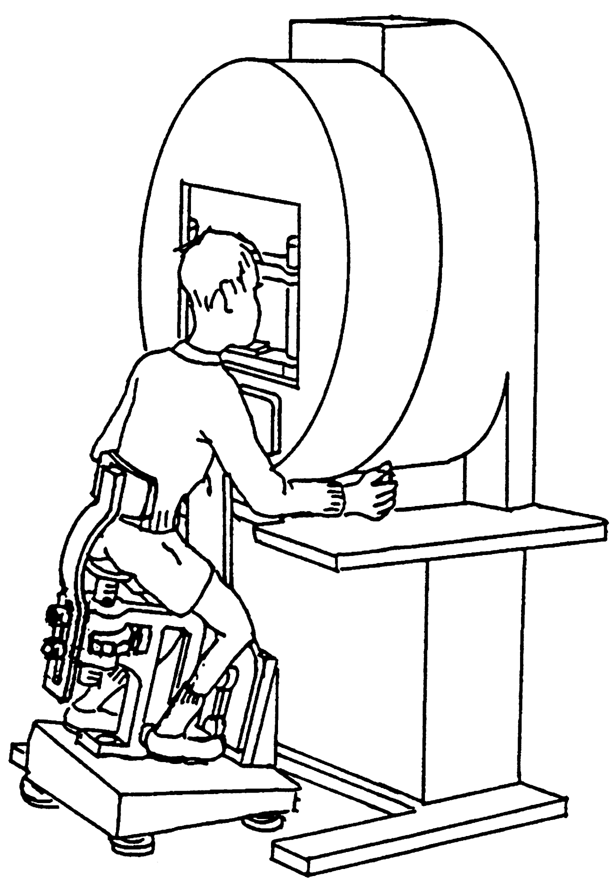

Fig. 1. Child's sitting position.

Table 1
Successive phases of the familiarization procedure

Purpose	Phases	Test-trials	Stimulus intensity	Number of trials
Training to perceive stimuli projected onto the periphery while maintaining central fixation	1	Stimulus projection	Maximal intensity (0 dB, i.e. 1000 Asb)	Adapted to enable the subject to succeed in the task
	2	Stimulus projection	Supra-threshold stimulus	Adapted to enable the subject to succeed in the task
Training to respond to the visual stimuli rather than to the clicks	3	Stimulus projection plus false-positive catch-trials	Maximal intensity (0 dB, i.e. 1000 Asb)	24 trials = 12 stimuli trials plus 12 false-positive catch-trials
	4	Stimulus projection plus false-positive catch-trials	Supra-threshold stimulus	24 trials = 12 stimuli trials plus 12 false-positive catch-trials

successive phases (Table 1), in which a subset of 12 locations were tested with different modalities. These locations were placed symmetrically on the 45°–225° and 135°–315° meridians at eccentricities of 5°, 10°, and 15°. Phase 1: using the maximum intensity permitted by the perimeter (0 dB = 1000 Asb), the subject was introduced to the double task of fixating the central target and paying attention to the stimuli projected onto the periphery. The number of trials depended on the time required by the subject to meet the criterion of detecting 5 consecutive stimuli without ocular movements greater than 3° [13]. Phase 2: identical to phase 1, but with supra-threshold stimuli (ST-stimuli). Intensities were set at 23 dB for locations with 5° eccentricity, 21 dB for locations with 10° eccentricity, 20 dB for locations in the lower hemi-field with 15° eccentricity, and 19 dB for locations in the upper hemi-field with 15° eccentricity. Phase 3: a sequence of 24 trials, including, in a random order, 12 maximum-intensity stimuli (one for each of the 12 selected locations) and 12 false-positive catch-trials. In this phase, the subject was introduced to the use of the response buzzer. Responses were followed by a verbal feedback until three successive correct responses were given. Phase 4: identical to phase 3, but using ST-stimuli.

The subsequent examination phase consisted of 15 successive identical blocks of 27 trials. Each block included, in a random order, 12 ST-stimulus trials, 12 false-positive catch-trials and three false-negative catch-trials. The examination was stopped before the end if signs of fatigue appeared. These signs included: pronounced and sustained fixation instability, ocular movements occurring systematically in more than 10 consecutive trials, and postural instability, with the child moving his/her head away from the headrest. The examination was also stopped if the child so wished. In both the familiarization phase and the examination phase, the sequence of trials was self-paced, stimuli being presented about 2 s. after the preceding response. The average total duration of the evaluation (familiarization and examination) was about half an hour.

3. Results

The test could not be performed in 5 of the 106 subjects (four 5-year-olds and one 6-year-old) because of technical problems (three children) or interruption of the procedure shortly after the test had begun, at the child's request (two children).

3.1. Training

To estimate the amount of training required at each age, we took into account two factors: (1) the number of trials before meeting the criteria in phases 1 and 2 of the familiarization procedure; and (2) the failure rates (false-positives, false-negatives, and no-response to ST-stimuli) computed separately in the last part of the familiarization procedure (phases 3 and 4) and in the first five blocks of the examination phase.

The number of trials required to meet the criteria in phases 1 and 2 varied significantly as a function of age: 26 and 24 at 5 years; 22 and 19 at 6 years; 19 and 16 at 7 and 8 years (average for the two phases: $F(3;97) = 13.12$; $P < 0.001$). Five-year-olds needed significantly more trials to meet the criteria than did older children (MANOVA, contrast analysis: $t = 5.63$; $P < 0.001$). For children aged 6 years and older, the number of trials required decreased slightly between the two phases ($F(1;97) = 21.01$; $P < 0.001$). However, the decrease was not significant for 5-year-old children ($F(1;22) = 1.19$; $P > 0.05$).

Fig. 2 shows the rates of false-positives (A) and no-response (B) during phases 3 (0 dB stimuli) and 4 (ST-stimuli) of the familiarization procedure, and during the first five blocks of the examination phase (ST-stimuli). In C are shown the rates of false-negatives in the first five examination blocks. False-positive rates decreased significantly between phases 3 and 4 ($F(1;97) = 30.16$; $P < 0.001$) then tended toward a stable level at the beginning of the examination (Wilks' $\lambda = 0.963$; $F(4;85) = 0.801$; $P > 0.05$). The no-response

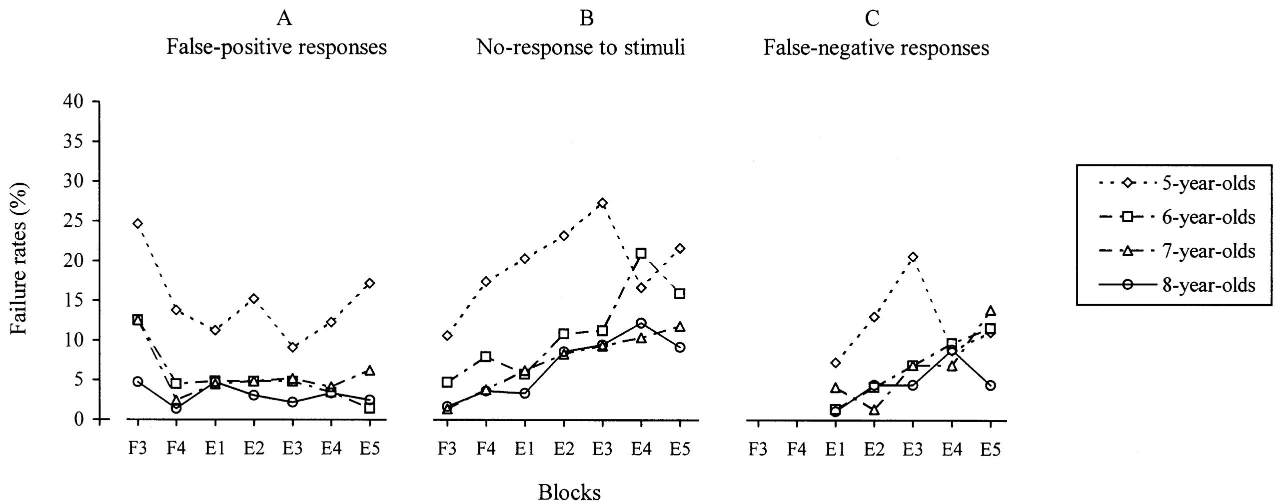

Fig. 2. Mean rates of false-positives, false-negatives, and no-response to stimuli, as a function of age, during phases 3 and 4 of the familiarization procedure and during the first five blocks of the examination phase. F3 and F4 = phases 3 and 4 of the familiarization procedure. E1–E5 = first to fifth blocks of the examination phase.

rate increased between phases 3 and 4 ($F(1;97) = 9.08$; $P < 0.01$), and continued to increase as a function of the block number (Wilks' $\lambda = 0.772$; $F(4;85) = 6.26$; $P < 0.001$). False-negative responses also increased as a function of block number (Wilks' $\lambda = 0.83$; $F(4;85) = 4.34$; $P < 0.01$).

3.2. Reliability

The reliability of the child's performance was evaluated by computing separately the failure rates over all available blocks (Fig. 3). Age had a marked effect on each type (false-positives: $F(3;97) = 8.24$; $P < 0.001$; false-negatives: $F(3;97) = 2.81$; $P < 0.05$; no-response to ST-stimuli: $F(3;97) = 10.68$; $P < 0.001$). Significantly higher rates were observed in 5-year-olds than in older children (MANOVA, contrast analysis false-positives: $t = 4.26$; $P < 0.001$; false-negatives: $t = 2.63$; $P \leq 0.01$; no-response to ST-stimuli: $t = 3.28$; $P < 0.01$). The probability of missing ST-stimuli increased markedly with eccentricity ($F(2;96) = 13.27$; $P < 0.05$). With the exception of five 5-year-olds and one 6-year-old, false-positive rates were less than 20%. There was no significant difference between boys and girls in any of the failure rates.

3.3. Endurance

Endurance (i.e. the acceptable duration of the examination) was estimated in two ways. First, by measuring the number of blocks performed by each subject; second, by comparing the average response rates over the last two blocks with the average response rates over the other blocks. Fig. 4 shows the mean number of blocks performed as a function of age. Endurance increased significantly between the ages of 5 and 8 years ($F(3;97) = 28.87$; $P < 0.001$). Polynomial contrast analysis indicated a linear developmental trend ($t = 9.204$; $P < 0.001$) from 6.2 blocks (167 trials) at age 5 to 13.2 blocks (356 trials) at age 8. A MANOVA contrast post-hoc analysis revealed significant differences in endurance between 5- and 6-year-olds on the one hand ($t = -3.398$; $P < 0.001$) and 7- and 8-year-olds on the other ($t = -3.523$; $P < 0.001$). Endurance was not significantly different in boys and girls (MANOVA: $F(1;93) = 0.80$; $P > 0.05$).

For each type of failure, Fig. 5 compares the average rate in the last two blocks with the average over all other blocks. The results show that the rate of false-negatives and of no-response to ST-stimuli increased toward the end of the examination ($F(1;97) = 20.76$; $P < 0.001$; and $F(1;97) = 30.37$; $P < 0.001$, respectively). At age 5, the increase was 70% for false-negatives and 20% for no-response to ST-stimuli. At all other ages, both increases exceeded 60%. False-positive rates, however, did not increase toward the end of the examination.

4. Discussion

There is still widespread skepticism about using automated static perimetry in young children. Our study demonstrated that, with the help of a carefully designed training and familiarization procedure, this method of visual field examination can be applied to most children as young as 5 years. The four-phase procedure, which we tested on a relatively large population of young children, proved effective on three counts.

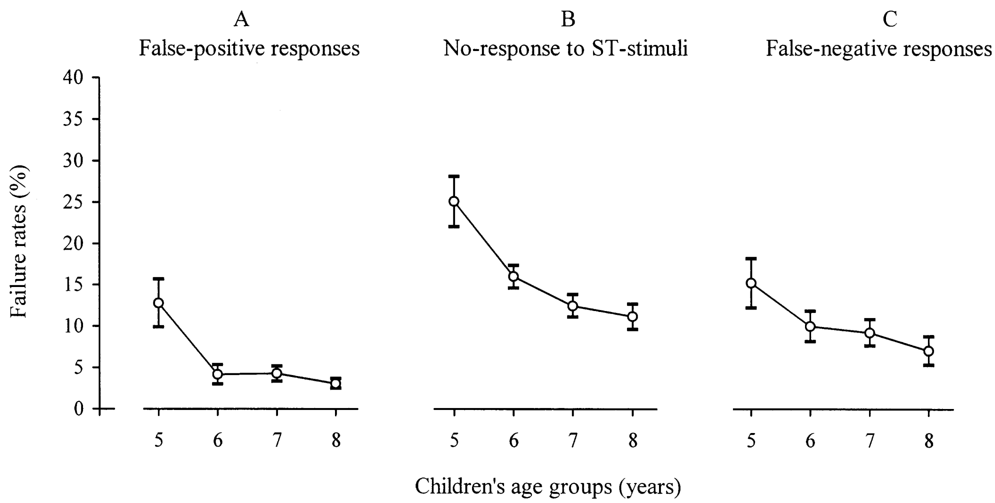

Fig. 3. Mean rates and standard error of false-positives, false-negatives, and no-response to ST-stimuli as a function of age. FP: Effect of age ($F(3;97) = 8.24$; $P < 0.001$). No-response to ST-stimuli: Effect of age ($F(3;97) = 10.68$; $P < 0.001$). FN: Effect of age ($F(3;97) = 2.81$; $P < 0.05$).

First and foremost, the training schedule was sufficient for most subjects to reach the level of reliability required for ASP examination. In adults, the standard criterion of reliability sets at 20% the maximum acceptable rate of false-positives [14]. On average, this criterion was met by even the youngest group of subjects, the rate for all other age groups actually being less than 5%. Secondly, the amount of training required to reach this level of proficiency was not inordinately large. At the most, 50 trials (on average) were sufficient to complete the first two phases of the procedure, the number being somewhat lower for the older children. Thirdly, the procedure enabled us to single out the various factors which affect performance, and which must be taken into account when testing this special population of subjects. Let us consider briefly some of the most salient factors that influence performance.

Maintaining a stable fixation on the central target, while at the same time paying attention to the peripheral stimuli, is by far the most taxing requirement of the examination, especially for 5-year-olds. This is consistent with the observation that, below age 5, it is difficult to inhibit the foveation saccades that are normally triggered by the sudden appearance of light stimuli in

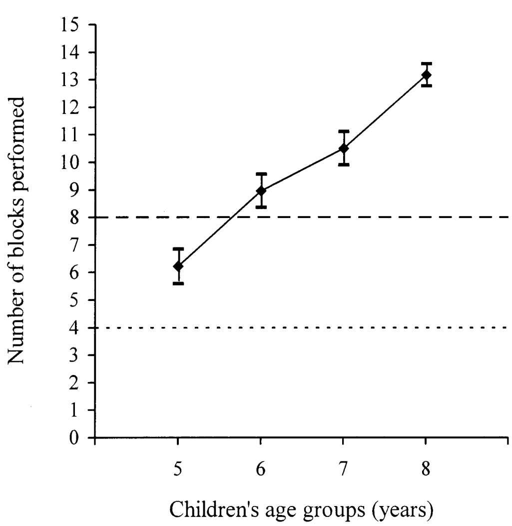

Fig. 4. Mean and standard error of the number of blocks performed as a function of age. Effect of age ($F(3;97) = 28.87$; $P < 0.001$). ..., approximate number of blocks corresponding to a regular screening procedure (108 trials). ---, approximate number of blocks corresponding to a regular quantified evaluation (216 trials).

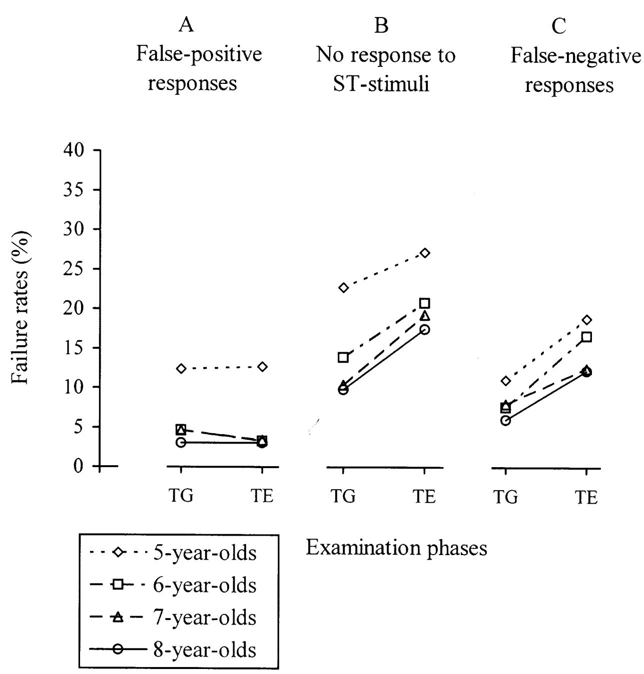

Fig. 5. Comparison of the average response rates over the last two blocks with the average response rates over the remaining blocks of the examination phase. Effect of time over false-negatives ($F(1;97) = 20.76$; $P < 0.001$), and no-response to ST-stimuli responses ($F(1;97) = 30.37$; $P < 0.001$).

the visual field [5–7]. The progressive emergence of voluntary inhibition during development was reflected in the concomitant reduction in the number of training trials for reaching the criteria. Maintaining a stable foveation on the central target may be one of the most difficult tasks for children. Recently, computerized procedures for improving stability have been devised. They include either a moving fixation target, which must be tracked using a joystick [3], or a brief display in the fixation square of a graphic symbol, which the subject has to name correctly [4] for the test to proceed. Since none of these methods are suitable for the use of available perimeters, a study is underway to evaluate post-factum the attained fixation stability in children.

The sequential use of both 0 dB and ST stimuli appeared to be beneficial when training young children. The results suggested that the introduction of a new element in the experimental condition resulted in a temporary drop in performance. For instance, the significant increase in no-response rates between phases 3 and 4 may be related to the concurrent change in stimulus intensity. Although both ST and 0 dB stimuli were clearly visible, the simple and seemingly irrelevant fact of changing this task parameter was perceived as a disturbing factor.

Another factor is endurance. In adult patients, the ASP screening procedure requires about 100 trials (i.e. 4 of our blocks). At least 200 trials (i.e. eight blocks) are required for a full quantitative evaluation. The effects of endurance can be summarized as follows: (1) 80% of 5-year-olds, and all older children are able to undergo a regular screening procedure; (2) a regular quantified examination is possible in 40% of 5-year-olds, 70% of 6-year-olds, 90% of 7-year-olds, and all 8-year-olds. A similar age-related improvement in endurance was demonstrated by Levy [15] when the continuous performance test [16] was administered to normal children aged between 4 and 7. In spite of these fairly encouraging results, the signs of fatigue shown by many subjects strongly suggest the need for continuous monitoring of this factor. In our study, the most conspicuous sign of fatigue was the relatively high rates of no-response to ST-stimuli, and of false-negatives (Fig. 2). Averaged across the first five blocks of the examination phase (completed by all subjects) the no-response rate for ST-stimuli was about 22% in 5-year-olds, and about 10% in older children. The corresponding averages for false-negatives were 12% and 6%. Since normative values for children are not yet well defined, these results may partly reflect age-related changes in sensitivity. However, the facts that both no-responses and false-negatives became significantly more frequent as the examination progressed, and that performance dropped significantly in the last two blocks of the test phase (Fig. 5), clearly demonstrate a progressive deterioration in perceptuo-motor performance. In reporting a similar decline in accuracy in the course of examination, McKay [17] suggested that fatigue may affect the level of vigilance. Moreover, fatigue may also manifest itself as a reduction in the size of the attentional field. Indeed we found, throughout the test, that the probability of missing ST or 0 dB stimuli was greater at locations with high eccentricity.

The last point deserving consideration is age. Overall performance improved rather markedly between the age of 5 and 6 years. However, the most striking characteristic among 5-year-olds was the large intragroup variability. Some children showed a high level of reliability, attentiveness, and consistency of response throughout the testing procedure, while others clearly showed insufficient reliability, suggesting that different performance profiles exist among the same age group. This issue should be fully investigated in a more controlled way, before addressing the question of the feasibility of automated perimetry in 5-years-olds.

The training and familiarization schedule tested here, while effective, should not be construed as a normative set of prescriptions. Some changes may be required in order to adapt the procedure to the age and health condition of the subjects. Let us consider some of the most important changes outlined by the present results (Table 2):

(1) Taking the rate of false-positives as the relevant index, we found that learning was mostly restricted to the two familiarization phases. Thus, the results in 8-year-olds suggest that the number of training trials in phases 3 and 4 could be reduced for this age group.

(2) In this study, training and examination took place in a single session. To overcome the problem of fatigue, two separate sessions could be envisaged for the youngest children. Indeed, in the second part of this study [12], in which training and testing were carried out one week apart, we found a marked improvement in reliability. A similar improvement was observed in adults undergoing visual field test-retest evaluations [18].

(3) An estimation of the number of trials that could be completed by children was based on monocular testing. Two separate test sessions may be necessary when visual field size or thresholds must be evaluated in both eyes, as is generally the case in clinical practice.

(4) A significant increase in false-negatives and no-response to ST-stimuli indicates that the examination is no longer reliable, and should be stopped. For children aged 5–8 years, a reasonable criterion for stopping the examination may be a 50% increase in false-negatives and/or a 50% increase in misses between two blocks.

(5) Vigilance may be severely disrupted, especially in younger children, by the high number of consecutive misses that are likely to occur when a sequence of stimuli fall within an altered area of the visual field. This can be prevented by modifying the algorithm that

Table 2
Recommendation for testing children

		5-year-olds	6-year-olds	7-year-olds	8-year-olds
Number of sessions required		3	3	2	2
Learning	Phase 1 (0 dB stimuli)	24 Stim		20 stim	
	Phase 2 (ST-stimuli)	24 stim		20 stim	
	Phase 3 (0 dB stimuli)	24 trials = 12 stim + 12 FP		24 trials = 12 stim + 12 FP	
	Phase 4 (ST-stimuli)	24 trials = 12 stim + 12 FP		12 trials = 6 stim + 6 FP	
	Phase 5 (ST-stimuli)	at least 3x 27 trials (12 stim + 12 FP + 3 FN)		None	
Examination	Testing strategy	ASP:2-level strategy or manual perimetry	ASP: partial/full quantified examination		
	Mean number of trials	170	240	280	360
	Stopping criterion	50% increase in FN responses			

Stim, stimuli trials; FP, false-positive catch-trials; FN, false-negative catch-trials.

schedules the location of the stimuli so, to avoid repeated testing of a limited area.

(6) Children with neurological diseases are often disadvantaged with respect to learning, endurance, and vigilance. For example, information processing [19], motor response, and response selection [20] are generally impaired after severe head injuries. More specifically, visual defects may have a negative effect on stimulus selection and on the inhibition of irrelevant responses. The intensity of ST-stimuli, and the prominence of the fixation point, should be adjusted to the severity of the impairment. In young patients, especially those aged 5 years, manual perimetry performed by an experienced perimetrist, although more subjective than automated static perimetry, may yield better results [21,22].

Acknowledgements

Appreciation is expressed to A.-K. Altrichter, K. Braff-Mayer, D. Desangle, J. Favre Dosso, F. Junker, T. Kirsch, G.L. Laffi, C. Moser, S. Musy, E. Ragama, P. Vindras, C. de Weisse, the Child Health Service of Geneva and the children and teachers of the Geneva public schools, whose collaboration has made this research possible. This work was undertaken with the financial support of the Swiss National Fund for Scientific Research, Grant # 32-36578.92.

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